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BEAM-ME

Computing energy system transformation pathways with high spatial and temporal resolution

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Systems Analysis and Technology Assessment

A PROJECT BY

HLRS

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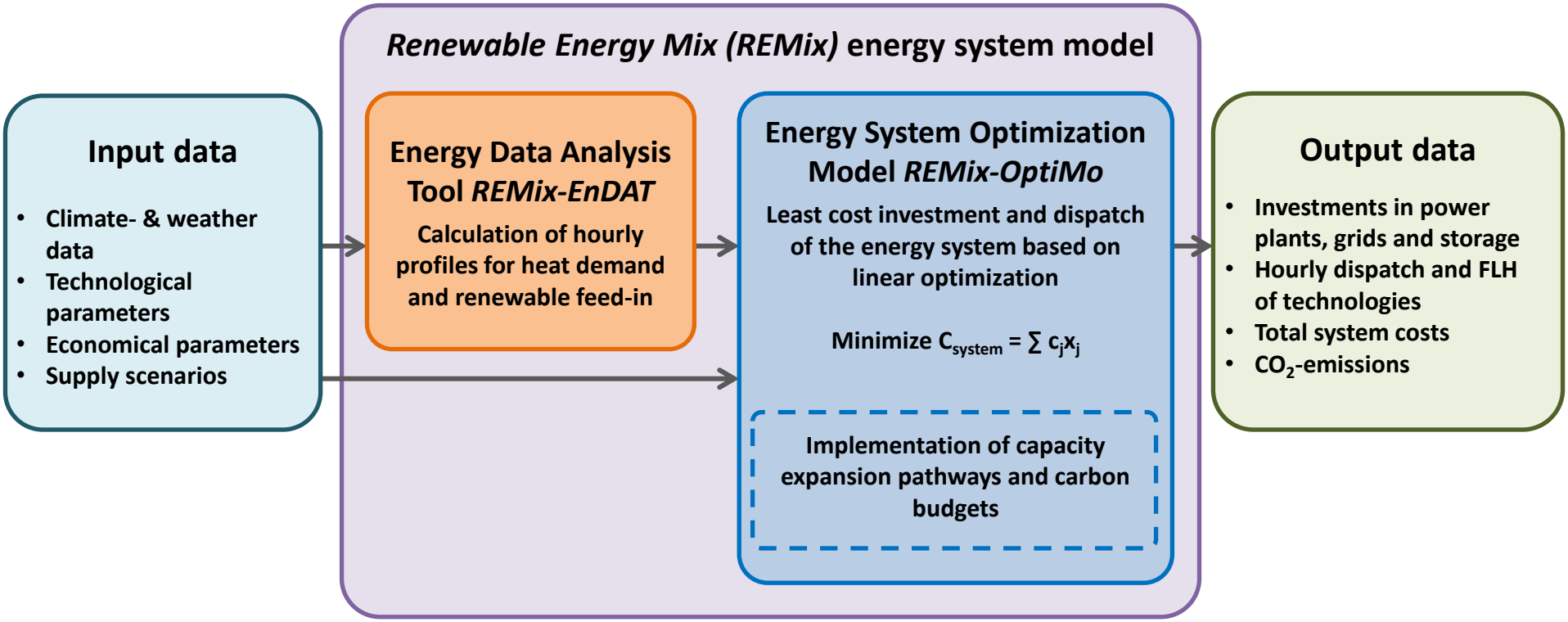
FORSCHUNGSZENTRUM

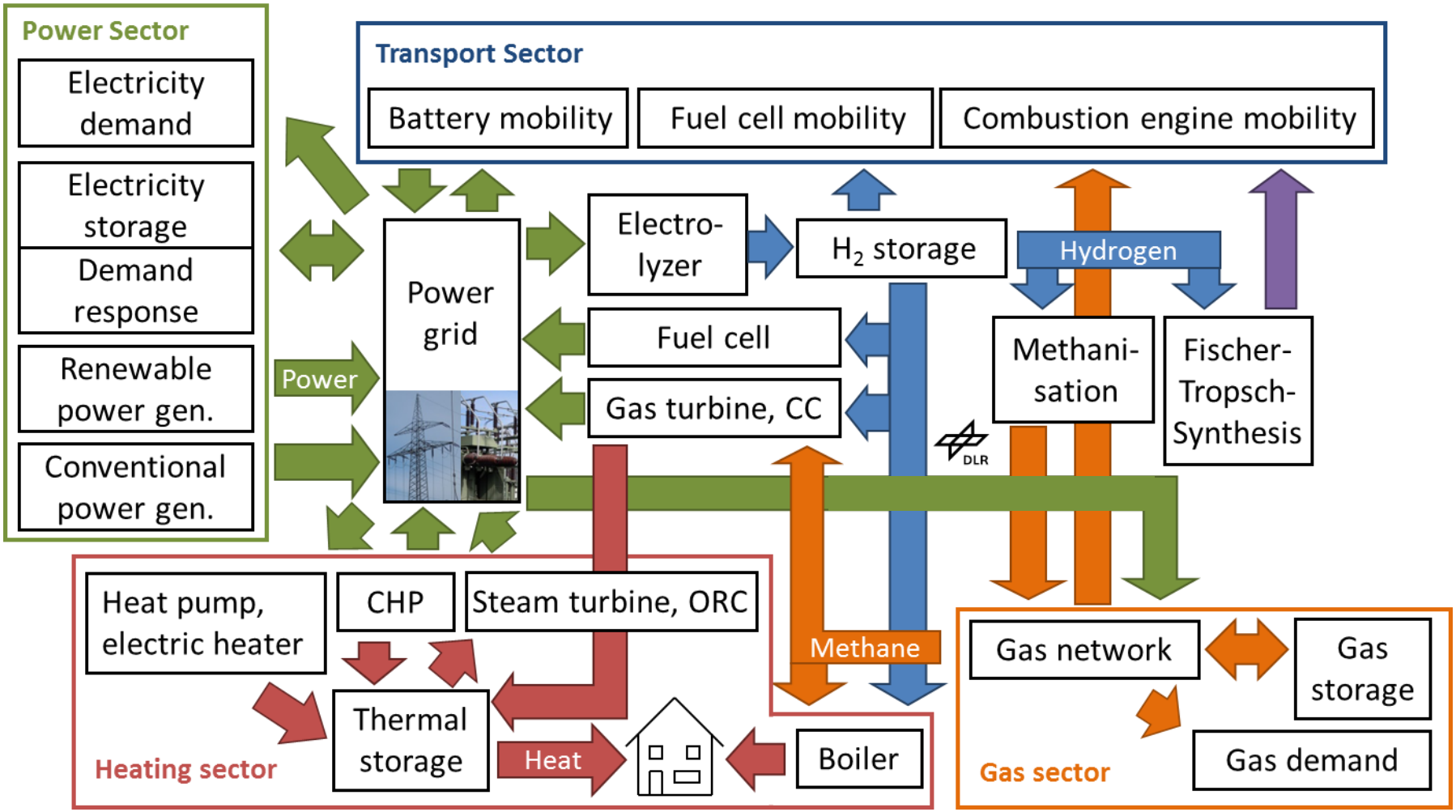
DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

ZIB

The energy system model REMix

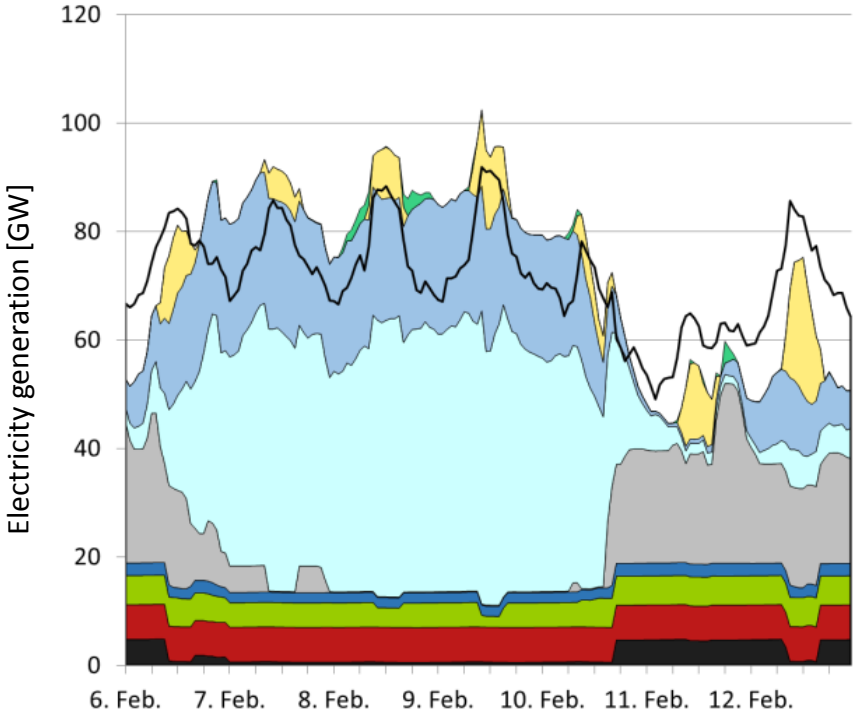


Increasing energy system complexity



Dimensionality of REMix problems

60 geographical regions,
86 AC transmission lines,
128 HVDC transmission lines



~ 30 technology levels with
8760 time steps per year

- Typical problems with up to 120 E6 variables and constraints
- Hourly dispatch is the computationally most demanding feature

Representing time in ESMs

Target-year optimization

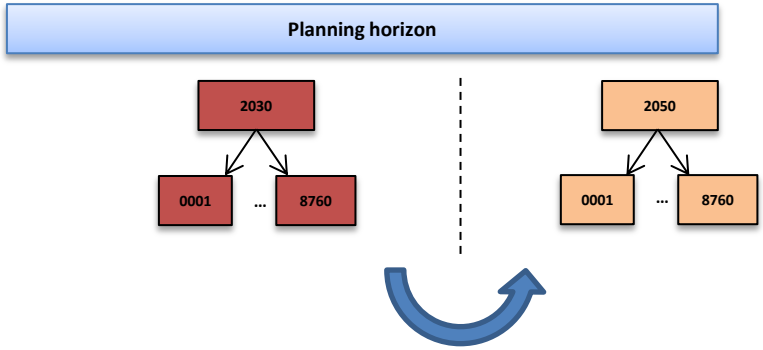
using full hourly time resolution

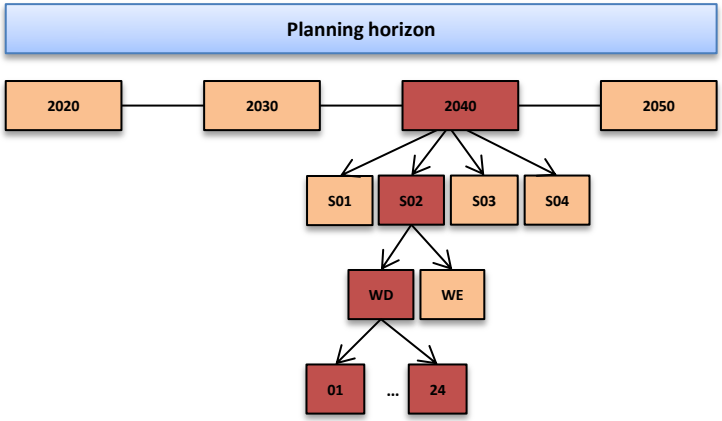
+ fluctuating renewable energies
+ flexibility options
+ hourly security of supply
- transformation path is implied
- sensitivity analysis to show robustness

Multi-year planning horizons

using representative weeks / hours / days

+ avoids technological lock-in
+ integral carbon budgets
- flexibility options
- delayed invests with technological learning





What is the systematic bias introduced by the two approaches?

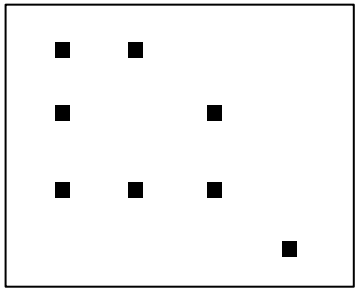
→ **Solve the integrated problem as a reference**

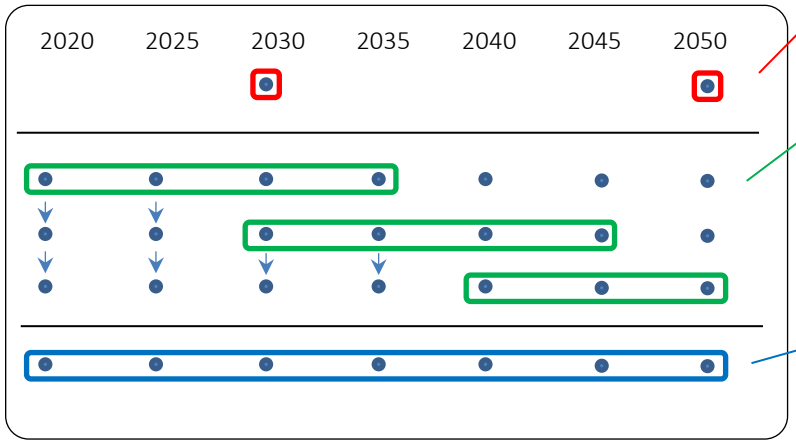
Plotting the matrix structure

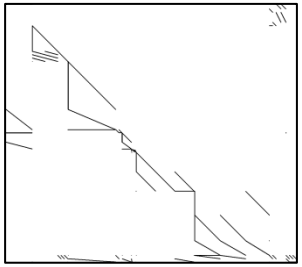
$$\min c \cdot x$$
$$A \cdot x \leq b$$

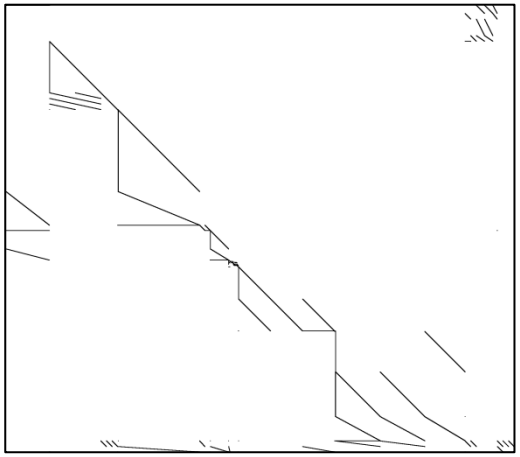
$c_1 \cdot x_1 + c_2 \cdot x_2 + c_3 \cdot x_3 + c_4 \cdot x_4$

$$\begin{array}{ll} a_{11} \cdot x_1 + a_{12} \cdot x_2 & \leq b_1 \\ a_{21} \cdot x_1 + a_{23} \cdot x_3 & \leq b_2 \\ a_{31} \cdot x_2 + a_{32} \cdot x_2 + a_{33} \cdot x_3 & \leq b_3 \\ a_{44} \cdot x_4 & \leq b_4 \end{array}$$









The limits of linear optimization

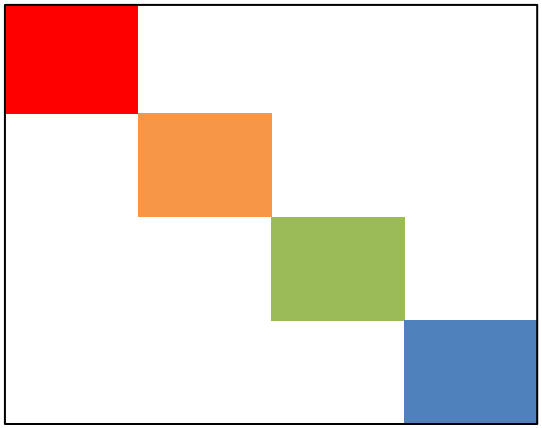
Planning horizon	1 year	4 years	8 years	12 years
Variables	54.5 E6	218.2 E6	429.0 E6	640 E6
Constraints	47.2 E6	188.2 E6	371.6 E6	560 E6
Nonzeros	199.8 E6	795.5 E6	1585.6 E6	2400 E6

XPRESS barrier: 2 TB RAM, 26 h
CPLEX simplex: 500 GB RAM, 24 h+

No barrier run possible with 2 TB RAM

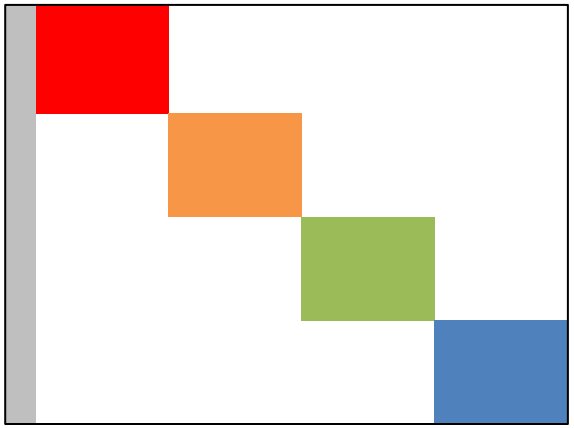
GAMS reports -1,9 bio. non-zeroes

Identifying matrix structures



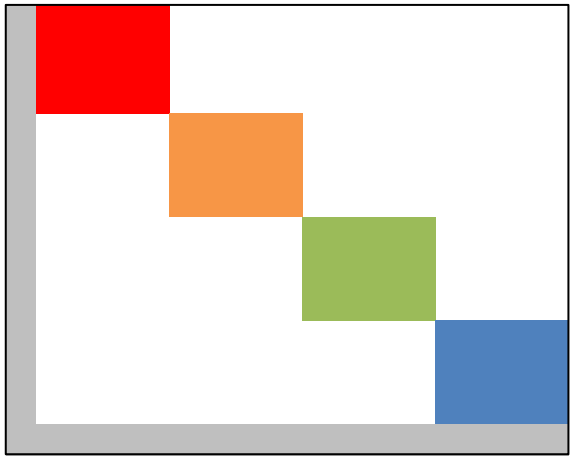
Disintegrated problem

Simultaneous solving of individual blocks



Stochastic problem

Individual blocks connected by first stage decision



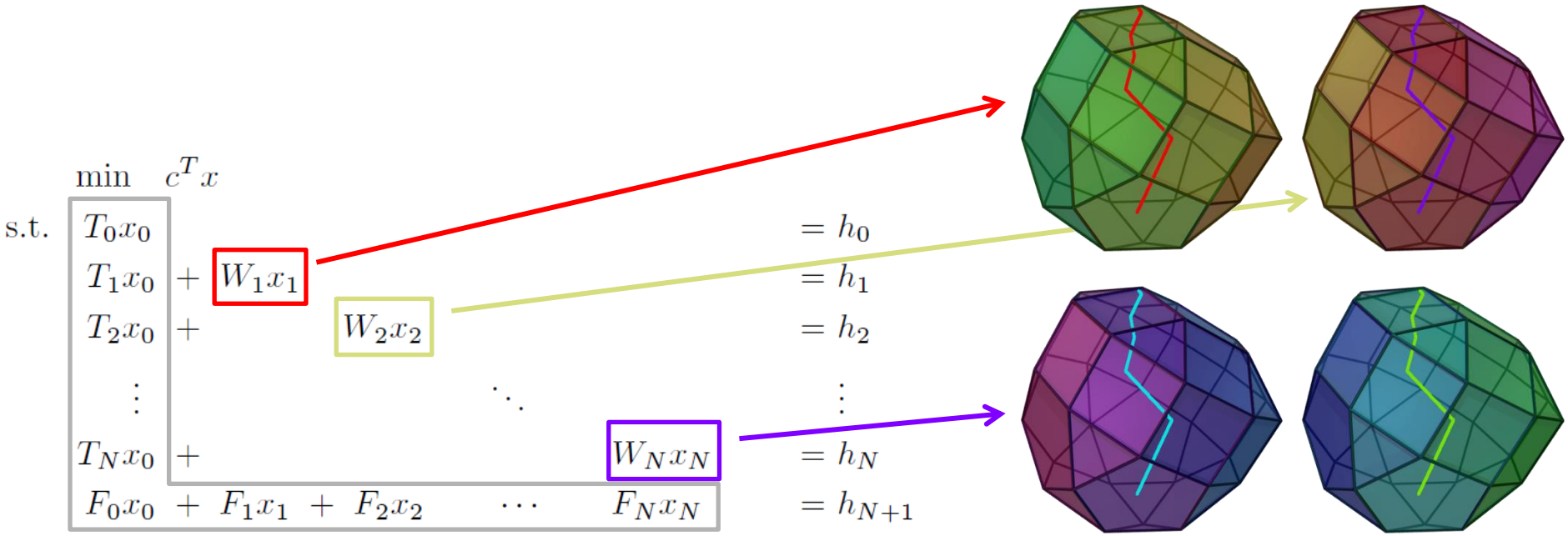
Block stuctured problem

Blocks connected by linking variables and constraints

?

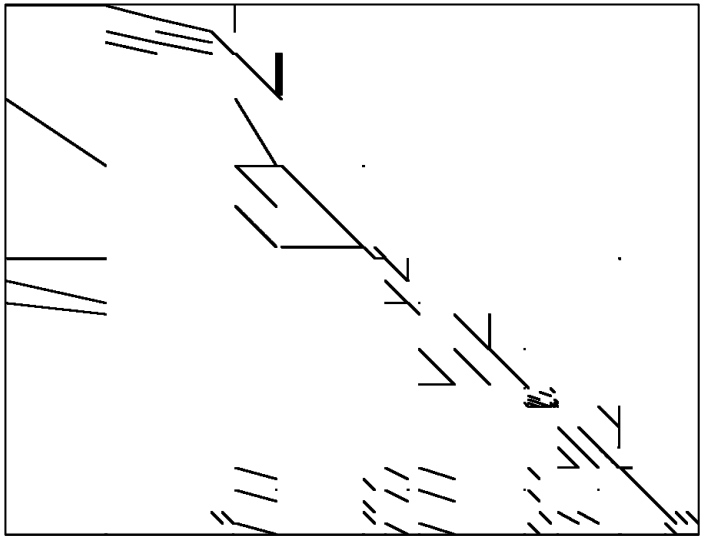
A parallel solver: PIPS-IPM

- Petra et al. 2014: *"Real-Time Stochastic Optimization of Complex Energy Systems on High-Performance Computers"*
- Ongoing solver development during the BEAM-ME project
- Structure of decomposition (annotation) required

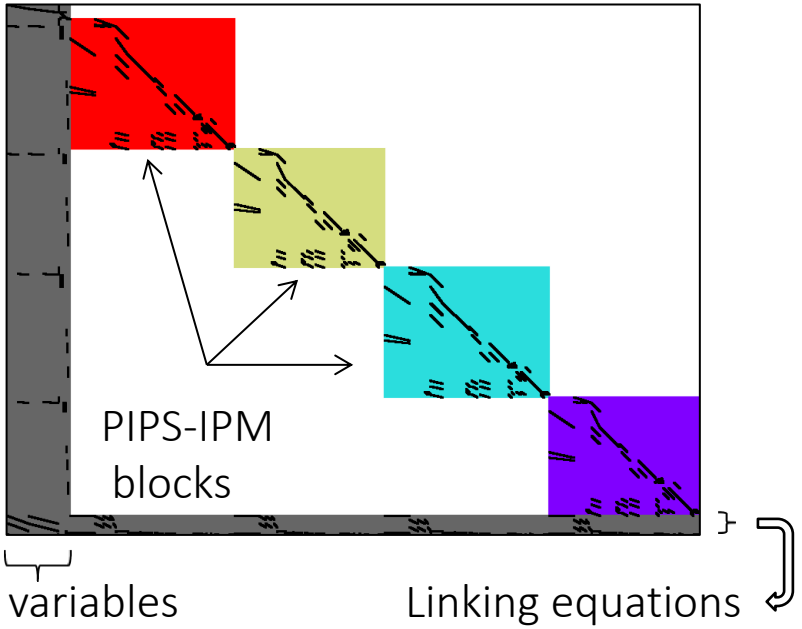


Problem specific structures for PIPS-IPM

Matrix of **non-zero entries** of REMix LP

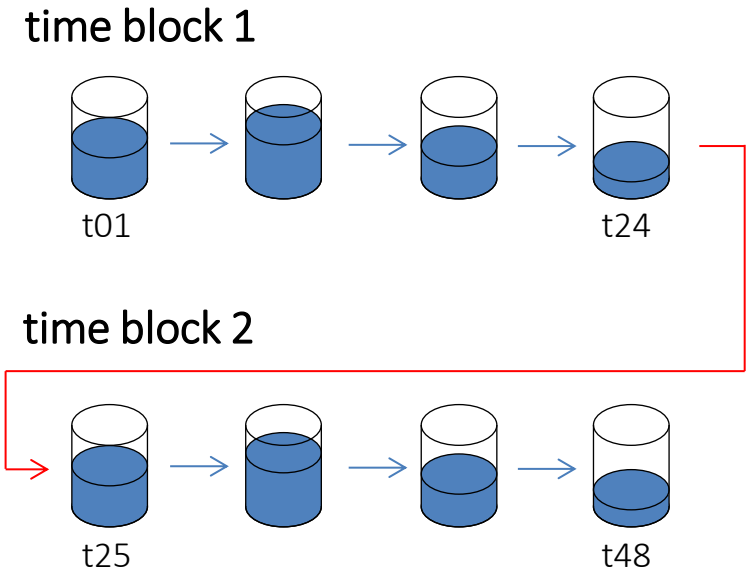


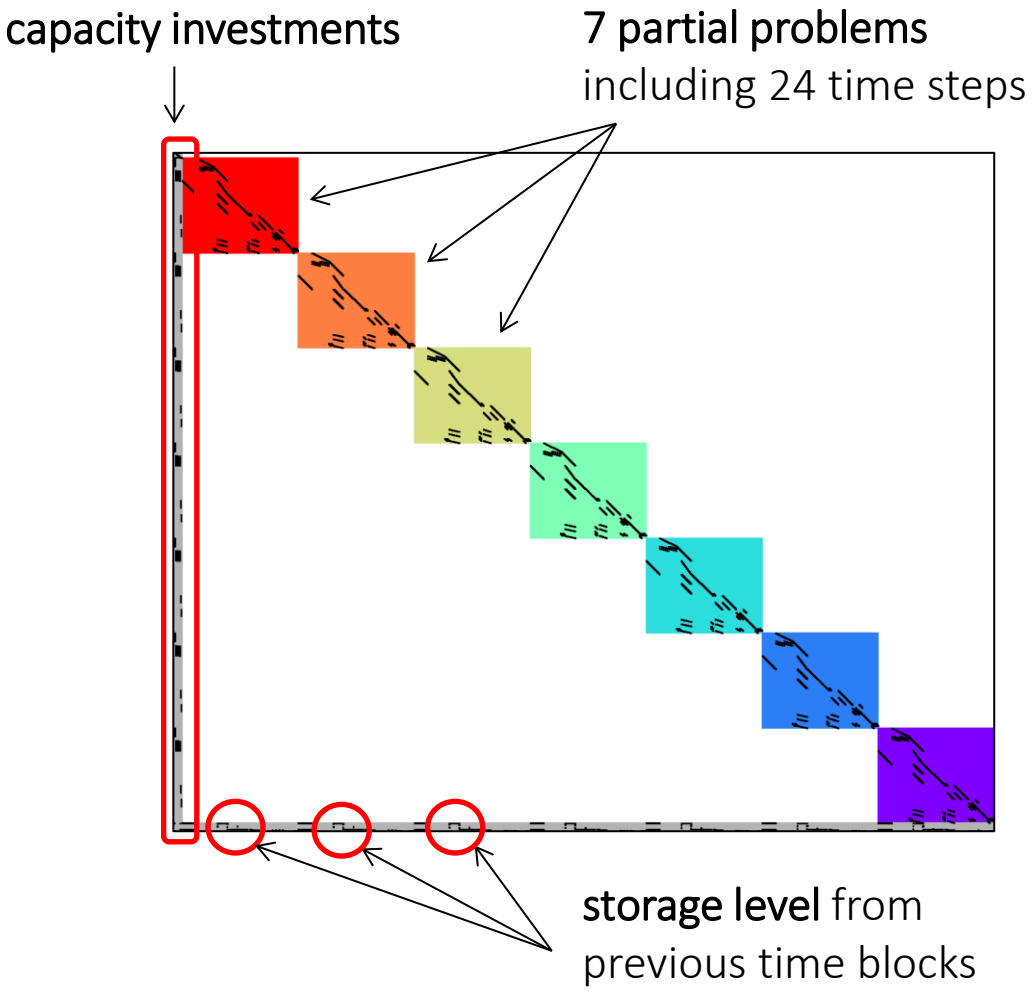
Permuted matrix revealing **block structure**



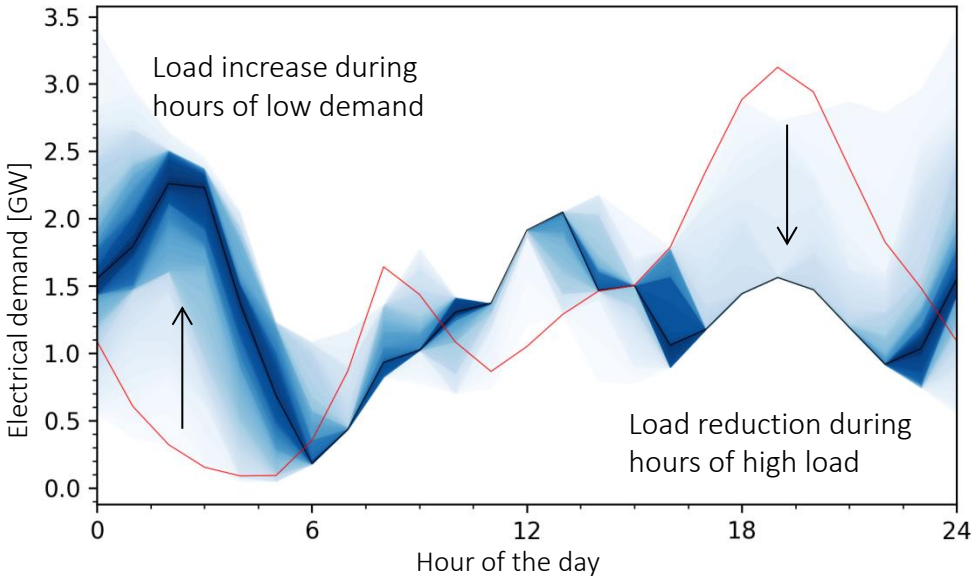
Annotation – temporal decomposition I

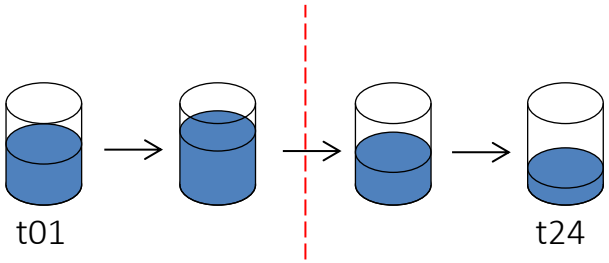
Linking by time: storage, load shifting, annual constraints





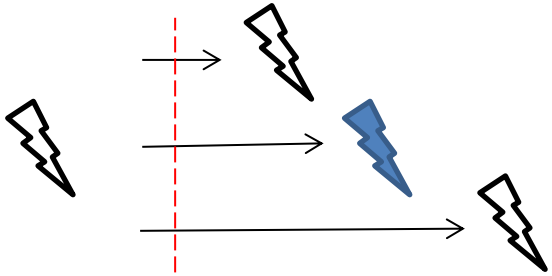
Annotation – temporal decomposition II





Storage equations link the storage levels

→ 1 link per time step

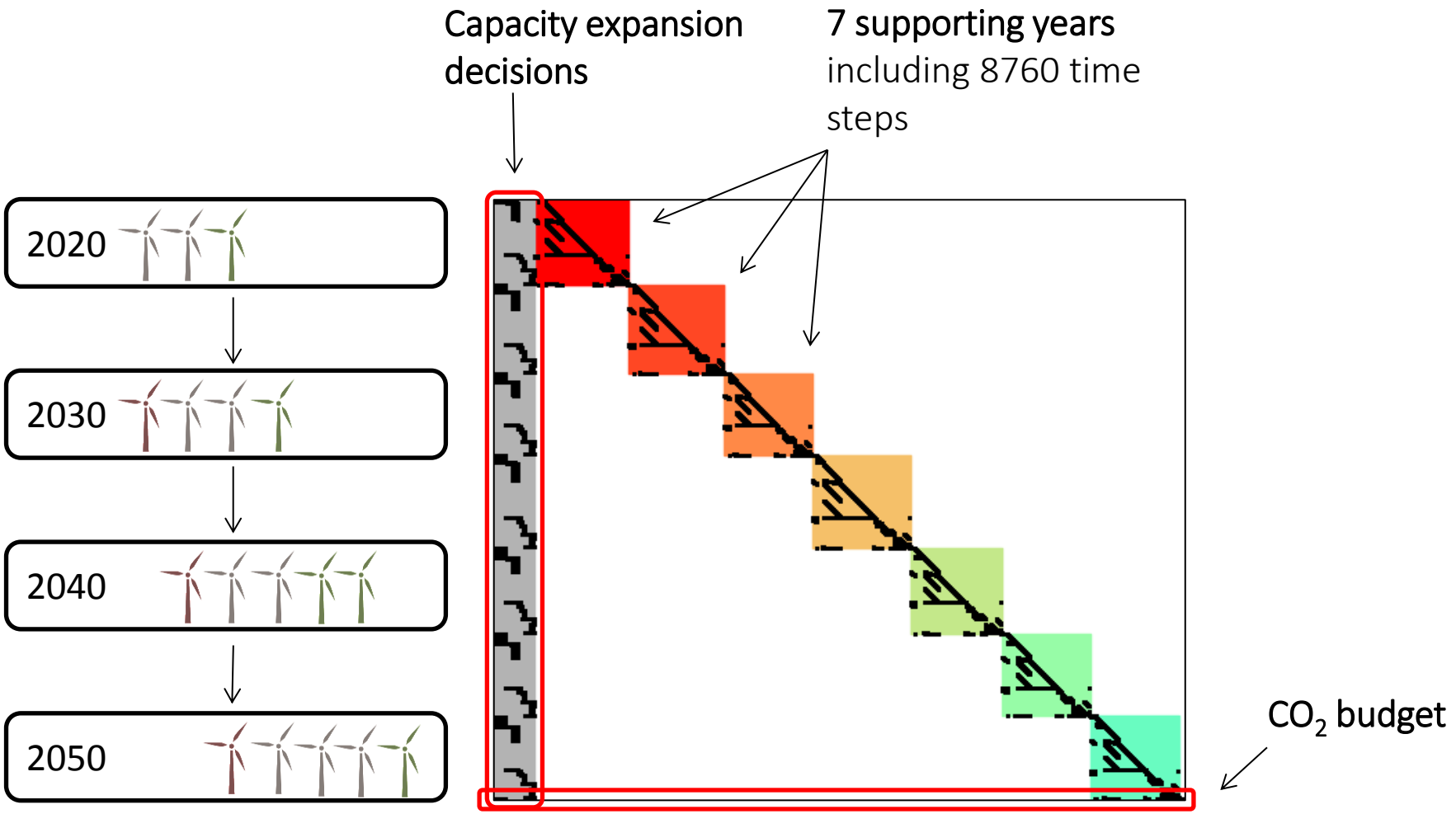


Shifting equations allow delaying of load

→ multiple links per time step

Annotation – planning horizon decomp.

Linking by years: construction and decommissioning of power plants, CO_2 budets



Current performance and outlook

- **Largest model** optimized with PIPS-IPM

  SIMPLE instance with **91 million variables, 90 million constraints**

CPLEX	**PIPS-IPM@JURECA**
Using 16 threads	2000 Cores
Aborted after 12 hours	Finished in 33 minutes

- Systematic evaluation of **solver performance** with different annotations
- Systematic **reduction of temporal resolutions** to evaluate adequate resolution

→ Smart modelling is always better…

(… if you know the error you make!)

Project BEAM-ME

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